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Validation of the Voice of America Coverage Analysis Program (VOACAP)

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

VALIDATION OF THE VOICE OF AMERICA COVERAGE ANALYSIS PROGRAM (VOACAP)

by

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February, 2013

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Prepared for: Naval Meteorology and Oceanography Command (CNMOC)
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14. ABSTRACT
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ABSTRACT

This is the final report of the COMNAVMETOCCOM Independent Model Review Panel (CIMREP) for the Voice of America Coverage Analysis Program (VOACAP), version 05.0119W, as modified by the Space and Naval Warfare Systems Center Pacific (SSC-Pacific), Atmospheric Propagation Branch (5528). VOACAP is a tool for predicting the performance of High Frequency (HF) radio communication systems. The authors evaluated VOACAP for possible inclusion in the Oceanography and Atmospheric Master Library (OAML) by (1) using provided and online documentation from HF experts, (2) installing the program on PCs, (3) running a series of test cases and (4) comparing the output results with other HF models and VOACAP versions.

The core physics and statistics in VOACAP are sound and this product could potentially be very useful to the US Navy. However several problems were identified related to (1) difficult installation of the program, (2) limitations on usable operating systems, (3) lack of ability to produce important output variables other than field strength, (4) inadequate documentation, and (5) the need for training and support for the successful use of the program or products derived from it. For these reasons, the authors cannot recommend inclusion of the submitted version of VOACAP in OAML. To make this possible, the Navy would need to provide more resources for the development of a suitable product, and support for the product once it has been included in OAML. These costs need to be weighed against the benefits of having an HF prediction product included in tactical decision aids such the Naval Integrated Tactical Environment Subsystem Next Generation (NITES-NEXT).

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I. Introduction

This is the final report of the COMNAVMETOCCOM Independent Model Review Panel (CIMREP) for the Voice of America Coverage Analysis Program (VOACAP), version 05.0119W, as modified by the Space and Naval Warfare Systems Center Pacific (SSC-Pacific), Atmospheric Propagation Branch (APB) (5528). This report contains a technical evaluation of the VOACAP model and accompanying documentation, with recommendations concerning inclusion in the Oceanographic and Atmospheric Master Library (OAML). VOACAP is a prediction tool for evaluating the performance of High Frequency (HF) radio systems.

VOACAP has a long history and has been validated and verified (V+V) by a variety of past studies including a quality assurance verification (QAV) performed by Lockheed Martin (2010a,b) and documentation provided OAML-SDD-96 (2010a,b,c,d). The authors of this current report are not specifically research HF experts, but P. Guest has extensive background knowledge of HF transmission issues and has taught a course covering this topic, designed instructional labs and online educational material regarding HF propagation since 1993. The authors are members of the Environmental Effects Group at the Naval Postgraduate School (NPS) in Monterey CA and have considerable experience developing and evaluating Navy environmental prediction products and tactical decision aids, writing computer code in PC and UNIX/LINUX environments and analyzing environmental effects on radio frequency (RF) propagation. The authors determined that because of the considerable previous V+V efforts performed for VOACAP, it was not necessary, nor fiscally justifiable, to convene a special committee of experts to perform this CIMREP. Instead the authors consulted with online and other sources to produce this report, in addition to performing several analyses of their own.

The outline of this report generally follows the recommended format with some modifications. After this introduction, this report presents some background information on HF propagation and VOACAP, followed by the approach taken, the findings of the study, the changes required, feedback from the developer, and final conclusions and recommendation for inclusion in OAML.

II. Background

A. HF Propagation

1. HF Primer

This section presents some essential background information for readers who may not be familiar with HF communications. HF (sometimes referred to as “short-wave”) communications were the primary form of long range communications before the satellite era. Although HF refers to “High Frequency”, the 2 MHz – 30 MHz frequency range represented by HF is lower (and has longer wavelengths) than most forms of communication today. HF signals can propagate in a variety of modes, including sky wave, space wave, surface wave and surface-reflected wave (the latter three often referred to collectively as “ground waves”). Space waves are direct line of sight (as modified by refraction) paths; for HF these are usually cancelled out by the surface-reflected wave and therefore neither can be used for HF communication. The surface wave is created by differences in the dielectric and permitivity characteristics of the air and ground which creates a “channel” for guiding the waves. Surface waves are an important aspect of HF communications and allow RF energy to travel over the horizon for medium distance (~0 - 500 km) communications (or radar). Commercial AM radio (in the MF band) is an example of a communication system that relies on surface waves.

A unique aspect of HF radiation is the ability to propagate in the form of sky waves. Sky waves refract, i.e. bend downward (hereafter called a “reflection”) in the ionosphere due to the presence of charged particles, primarily free electrons. The reflection occurs in the F (during the day subdivided into F1 and F2) layer in the atmosphere which exists in the region 150-800 km above the surface. During daylight hours, reflections can sometimes occur in the E layer which is just below the F layer, 90 – 150 km above the surface. The D-layer, 60 – 90 km above the surface, absorbs HF energy in the daytime and limits propagation ranges. Above a critical frequency, which depends on the free electron density, radio waves are no longer reflected and proceed into space, making skywaves transmission impossible. The frequency at which this occurs for a particular propagation angle is called the Maximum Usable Frequency or MUF. Another parameter often used is the Frequency of Optimum Transmission or FOT, defined as the MUF times 0.85. At lower frequencies, the radiation is absorbed in the D layer, depending on the frequency and the power of the transmitter (more power, greater ability to overcome the absorption). This lower limit is called the Lowest Usable Frequency or LUF. At night, D layer absorption is neglible and the LUF is usually set to an arbitrary value, such as 2 MHz. Between the LUF and the MUF, the radio waves will propagate through the D layer and reflect from somewhere within the F layer, thus allowing long range communications. Figure 1 shows some of these concepts.

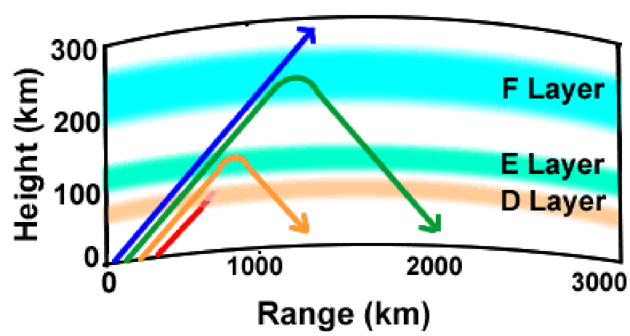

Figure 1 Ray trace diagram showing sky waves at different frequencies. The **blue** ray frequency is greater than the MUF and passes into space. The **green** ray frequency is less than the MUF but greater than the E layer MUF. This is usually the best frequency region to use for long range communications and is usually where the FOT (equal to 0.85 x MUF) exists. The **orange** ray frequency is less than the E layer MUF and greater than the LUF. This is best for mid-range (around 500 to 1500 km) transmissions. The **red** ray is a lower frequency than the LUF and is absorbed in the D layer.

A powerful enough signal can reflect or “bounce” off the surface and again propagate into the ionosphere, to be reflected downward again. A typical F layer bounce occurs about 2000 km from the transmitter; multiple bounces can propagate all around the world if conditions are right. Between the bounce regions, (especially before the first bounce) are “skip zones” where HF communications fail. It is the ability to reflect off the ionosphere and propagate for long distances that makes HF communications such a powerful tool.

Complicating the issue, events originating from the sun (called “space weather”) can affect the ionospheric electron density and therefore the value of the MUF and LUF. Some space weather events follow a more or less regular 11 year cycle (as indicated by sunspots) while others, such as geomagnetic storms, are less predictable. Sometimes conditions produce a condition where the MUF is lower than the LUF. During these situations, called “short wave fadeouts”, HF skywave communications are not possible. Another complication is interference by human sources; this is a big problem in urban areas where there are many sources (mostly unintentional) of HF radiation “noise”.

The trick to performing successful HF communications is to choose a frequency higher than the LUF and lower than the MUF and to insure that the receiver is not in a skip zone. Unfortunately, the values of the MUF and LUF vary greatly in every 24 hour period, going up during the day and down at night. So it is not possible to pick a frequency that will work at all times of the day for a particular transmitter/receiver pair. This is where a model such as VOACAP comes into play. Such models predict the signal strengths and probability of successful communication based on the above discussion and other factors for a particular frequency. These models also predict the values of the LUF and MUF over a 24 hour cycle, so that HF operators can decide beforehand which frequencies (if any) are availble for use at for a particular time of day.

2. The Military and Civilian uses of HF

Before about 1965, HF was the primary form of long range communications, at least in areas not serviced by direct wire commications. With the advent of satellite communications (which use frequencies high enough to penetrate the ionosphere) the use of HF by the US Navy was drastically reduced. The US Army and Air Force continued to use HF, along with ham radio operators, but not to the extent as in previous years. The military use of HF is still very important in some allied countries, Australia being a notable example. There is also a concern in the US Navy that an adversary could destroy our communications satellites, which would make long range communication with our ships impossible, which would be a tactical and strategic disaster. For these reasons, there has been renewed interest within the US Navy to maintain a capability for HF communications. Due to the idiosyncrasies discussed in the previous sub-section, ,the use of HF also requires a reliable prediction capability; thus the need for including a HF prediction model in the OAML library.

B. VOACAP

1. Brief History

The Voice of America Coverage Analysis Program (VOACAP) traces its history back to the 1920's and 30's when HF communications first became an important method for long distance communications. During this period, the importance of ionospheric conditions became apparent and manual prediction techniques were developed. While successful, these techniques were laborious and time consuming. With the advent of computers, several automated prediction programs were developed, the first being ITSA-1 in 1966. By 1978, ITSA had evolved into the Ionosphere Communication Analysis and Prediction Program (IONCAP), developed by George Haydon, John Lloyd and Donald Lucas at the National Telecommunications and Information Administration, Institute for Telecommunications Services (NTIA/ITS), US Department of Commerce with funding and input from the US Army and other organizations. In the mid 1980's NTIA ceased work on IONCAP, but George Lane from Voice of America and Frank Rhoads from the Naval Research Laborator (NRL) in Washingtion DC were funded by the Voice of America (VOA) to continue development of an HF prediction program. The improved program developed by Lane and Rhoads officially became VOACAP in 1993 and has been used by VOA ever since. The core model has remained essentially unchanged from the 1993 version, although Greg Hand has implemented several improvements to the software package and environmental inputs, and currently maintains a web site documenting these changes and other information about VOACAP at http://www.greg-hand.com/hf.html. Note that Hand is retired from NTIS/ITS and provides support on a volunteer basis; he is the only person currently maintaining VOACAP. The historical information presented here is from OAML-SDD-96 (2010c), the "Luxerion" web site at http://www.astrosurf.com/luxorion/qsl-soft-voacap.htm and links in the "VOACAP Quick Guide" by Jari Perkiömäki (http://www.voacap.com). The reader is referred to these documents and web sites for details on VOACAP history. The main point is that VOACAP represents the culmination of many years of research and development and, despite not undergoing major changes in the physical and statistical representations for the last 20 years, it is still considered by many HF experts to be the "gold standard" for HF propagation programs.

2. Description

VOACAP is a probabilistic model that predicts HF propagation between a radio transmitter (Tx) and receiver (Rx) at any two points on Earth over a 24 hour cycle. It also predicts global areal coverage for a single Tx location and time. VOACAP predicts 22 parameters, including Signal-to-noise Ratio (SNR), Reliability (% chance of successful comms), Required Power Gain, Signal Power, Field Strength at Receiver, MUF, LUF and Propagation Angle. The VOACAP model is based on monthly averages of ionospheric conditions, Tx and Rx system characteristics, antenna and surrounding ground characteristics and man-made noise.

The ionospheric conditions are based on statistics from a huge number (from more than 35,000 locations) of observations compiled by the Comité Consultatif International des Radio Communications (CCIR), the International Union of Radio Science (URSI) and other sources, using inputs of sunspot number, 10 cm solar flux and the 3 hour planetary K-index, the latter being a measure of magnetic field fluctuations associated with solar activity. The program takes into account the diurnal and solar activity cycles. However, because VOACAP is primarily a statistical, empirically-based model, it does not attempt to predict solar weather events associated with coronal mass ejections (CME) and other space weather phenomena. The model does allow the input of a "multiplier" for free electron densities in the E, F1, F2 layers, which a knowledgeable user could use to account for space weather effects.

The Tx and Rx system characteristics used by VOACAP are quantified by several system parameters (see Appendix A for specifics). The original VOACAP (available from NTIA/ITS) contains a data base of hundreds of transmitter and receiver systems and a large number of antenna types. The original VOACAP also contains a detailed data set of atmospheric and man-made radio noise, as developed by A. D. Spalding. This estimate of radio noise is available for locations around the globe.

The information for this section is based on the informative "Quick Guide" web site developed and kept up-to-date by Perkiömäki (http://www.voacap.com). In addition to detailed descriptions of VOACAP and considerable other related information, this site allows the user to run the model online and produce color-contoured outputs of global areal coverage and 24 hour point-to-point predictions for a particular chosen path showing probability of communication for all HF frequencies. From the latter, the diurnal cycle of the MUF and LUF can be easily determined. Much of the information on the Perkiömäki web site was obtained from the book "Signal-to-noise Predictions Using VOACAP – A User's Guide" by George Lane developed under contract from Rockwell Collins (Lane, 2001). Lane's guide can be orderd in CD version from the site http://www.greg-hand.com/pc_hf/rockwell/.

3. VOACAP Implementation by SSC-Pacific

This CIMREP report is an evaluation of the VOACAP version that was implemented by the Atmospheric Propagation Branch (APB) 5528 of SSC-Pacific. The information in this section is based on four documents (VOACAP Software Test Description, Software Design Document, Software Requirements Specification and Software Modification Document) produced by the APB (OAML-SDD-96, 2010a,b,c,d) and a Quality Assurance Verification (QAV) Brief Summary, and Full Report by Lockheed Martin (2010a,b).

SSC-Pac ABP obtained VOACAP version 05.0119W from NTIA/ITS in 2009. APB SSC-Pac did not make any changes to the physical and statistical algorithms within the VOACAP model nor did they change any of the input parameter requirements. However, APM SSC-Pac made several modifications to the FORTRAN source code to meet Navy requirements for inclusion in the Naval Integrated Tactical Environment Subsystem Next Generation (NITES-NEXT) which is the tactical decision aid program of record (POR) of the Navy Program Executive Office (PEO C41). This effort was part of SSC-Pac plan to develop the Radio Frequency Propagation Service (RFPS) which is a service-oriented approach (SOA) for providing electromagnetic (EM) propagation models used by NITES-NEXT developers.

The original VOACAP (referring to the version obtained by SSC-Pac from NTIA/ITS) FORTRAN program used strict 80 column format with a specific output format. The file and folder names were based on early Microsoft DOS requirements. SSC-Pac modified the code so that it could compile using Intel Visual FORTRAN 10.2

and created dynamic link libraries (dll) for use in Microsoft Windows operating systems. To support data communications using dll files SSC-Pac removed all “SAVE” and “WRITE” statements and also restrictions on path, folder and file names. Several other changes, detailed in OAML-SDD-96 (2010b,d) and related to modernizing the FORTRAN code, were also performed. Some bugs including common block misalignments and noninitialized variables were fixed.

Instead of the fixed field formats for environmental data input and prediction outputs, the current SSC-Pac implementation of VOACAP uses XML formatted data structures (examples in Appendices A and B). The antenna specifications use two files: (1) a control file with a table of needed parameters for antenna performance and (2) a file with specific antenna parameters. The program first reads the control file which contains a reference to the specifc antenna parameters, thus allowing specification of the antenna angle and gain pattern.

Personnel from Lockheed Martin, Civil Programs, Space and Science Solutions, performed a Quality Assurance Verification (QAV) for the SSC-Pac implementation of VOACAP (Lockheed Martin, 2010a,b). Lockheed Martin compiled VOACAP using Intel Visual Fortran version 1.1 integrated with the Microsoft Visual Studio 2008 using a Dell pentium processor operating at 3.2 Ghz with 3.5 GB of RAM. The operating system was Microsoft Windows XP Professional Version 2002, Service Pack 2. Several changes were required to succesfully execute the compilied program. This included moving various files to different locations and the config.xml file had to be modified to point to the correct locations. Neither of the last two suggestions were implemented in the VOACAP version supplied to the authors of this CIMREP report. The authors also had to make some of these (and other) changes to make the program run properly, as detailed in a later section.

Various attempts by Lockheed Martin to compile the VOACAP source code in a Linux environment were unsuccessful due to the use of Intel record structures that were not supported by the varioius compilers that were tried. The QAV found that some of the output values were slightly different than expected. These differences were attributed to round off errors and were not significant.

The Lockheed Martin QAV report recommends VOACAP as a Navy standard within a Windows (PC) environment. They also recommend that the Intel Fortran record structures be converted into standard FORTRAN 95/90 data types for portability between compilers. Finally they recommend that a “makefile” be provided and the “software be modified and tested thoroughly within Unix/Linux environments before it is submitted for OAML approval.”

III. Approach

A. Meetings

As noted in the Introduction section of this report, the authors did not convene a special meeting with HF experts to evaluate VOACAP. It was felt that information provided by SSC – Pacific (OAML-SDD-96, 2010a,b,c,d) , the QAV report (Lockheed Martin, 2010b) and various online sources were sufficient to evaluate the suitability of

VOACAP for Navy uses. P. Guest did meet with the official developer of the program at SSC-Pacific to get feedback on the report findings , as described in Section VIII.

B. Criteria

1. Installation

The authors attempted to install the program on several different PCs and documented the steps required to make the program execute properly. The authors did not attempt to compile the supplied source code but instead used the FORTRAN executable code that was supplied. The authors evaluated the installation procedure, as described in the findings section below.

2. User Interface and Ease of Use

The authors evaluated and documented these factors as described below.

3. Accuracy of Prediction

It was not feasible to conduct an actual field test to verify the accuracy of the VOACAP. However based on its long history and continued use and recommendation by HF experts, it is our opinion that this is one of the most accurate and reliable HF prediction programs available today. The authors performed a series of tests to verify that the SSC-Pacific implementation performed as expected. Because the VOACAP CD did not include any graphics output, the authors wrote computer code using Matlab to parse the XML format output data and plot areal coverage and point-to-point results to allow for inspection of the results and comparison with other implementations of VOACAP.

The tests consisted of the following:

- Running the supplied version of VOACAP using inputs from the sample test case provided in the Software Test Description (OAML-SDD-96, 2010a) to verify that the output values were identical to those given in this document. There was one areal coverage and one point-to-point test case. The XML input files that were used in the two sample test cases are contained in Appendix A and the ouput files are in Appendix B.

- Comparing the plots of output data from these sample test cases with similar plots from the Advance Refractive Effects Prediction System (AREPS) tactical decision aid.

- Comparing the plots of output data from these sample test cases with similar plots from the online version of VOACAP at the Perkiömäki web site http://www.voacap.com.

- Comparing the plots of output data from these sample test cases with similar plots from Problab 2.0, which is a commercially-available stand-alone HF prediction program.

- Performing a series of test cases that explored the input parameter space, as specified in the Software Requirements Specification (OAML-SDD-96, 2010c). For these tests, the maximum and minimum value of a particular parameter were used as input into VOACAP. These included environmental parameters, EM system parameters and antenna parameters. In addition, the program was tested using different geographical locations, times of day and times of year. One aspect of the test was to see if the program crashed or produced errors by using extreme locations in the input parameter space. Another aspect was to detect potential bugs in the code by examining the output in a qualitative sense. Table 1, in section IV.E. below, shows the various test cases that were executed.

The results of these test are described in a later section.

C. Sources of Data

As described above, in addition to the two sample test cases, the authors varied the different input parameters, based on the provided allowable input ranges (see Table 1). Plots of results from the VOACAP predictions were compared with similar plots from AREPS, Proplab 2.0 and the online VOACAP.

IV. Findings

A. Installation

The installation procedure was time-consuming and not straightforward, requiring several days of effort and phone calls to SSC-Pacific to get the compiled version of VOACAP to properly execute. There was a readme.txt file (shown in Appendix C) on the provided CD but it was buried deep in the file structure and not easy to find. The readme.txt file did not contain all the needed information to install and run the program and the information provided was not easy to understand, at least for the authors who are environmental scientists, not computer system experts. There was also information about running the program in various locations of the supplied documents (OAML-SDD-96, 2010a,b,c,d). None of this information was complete, nor was it logically organized.

The name of the batch file that calls the executable FORTRAN program "RFPS_fileio.bat", is not intuitive to people not familiar with RFPS and it was buried three layers deep in the file structure. Some of the directory names were lengthy and cumbersome; these were modified by the authors for ease of use.

The authors had to perform the following steps to get the program to run without errors:

1. Modify the RFPS\Config.XML to specify where the files are: The original defaults were:

<SystemDatabase>C:\Documents and Settings\etheridgej\Desktop \VOACAP_QAV_ANALYSIS\QAV\RFPS_15\RFPS_15\Data\System\ArepsDatabase.XML</SystemDatabase>\

<DtedFolder>C:\Documents and Settings\etheridgej\Desktop \VOACAP_QAV_ANALYSIS\DTED</DtedFolder>

<DataFolder>C:\Documents and Settings\etheridgej\Desktop \VOACAP_QAV_ANALYSIS\QAV\RFPS_15\RFPS_15\Data</DataFolder>

These were changed to (changes indicated by red text):
<SystemDatabase>C:**VOACAP\VOACAP**\RFPS_15\RFPS_15\Data\System\ArepsDataBase.XML</SystemDatabase>
<DtedFolder>C:\ **DTED**</DtedFolder>
<DataFolder>C:**VOACAP\VOACAP**RFPS_15\RFPS_15\Data</DataFolder>

2. Copy the coeffs\ folder to the Ionosphere folder:

C:\ \VOACAP\VOACAP\RFPS_15\ RFPS_15\Data\Ionosphere\coeffs

3. Copy the coeffs folder also to RFPS_15\ and rename it Dcoeffs.

4. No DTED terrain data was provided with the CD. The authors had to obtain this from other sources and copy into the DtedFolder as shown in the config.XML.

The above required modifications were not clearly stated anywhere in the readme.txt file nor in any of the other documentation except for this general statement in the readme.txt file:

"3) You may have to modify C:\Program Files\RFPS\Config.XML to specify where your DTED folder is located."

B. Execution

After debugging and making these changes, the authors were able to run the program and produce the XML output files using a PC operating in a Windows XP environment. After several attempts using a variety of computers, it was determined that the supplied executable file could not run on PCs with Windows Vista, Windows 7 or Windows 8. In hindsight, this was not surprising, because the FORTRAN compiler used to create the executable was designed for Windows XP. However this information was not stated anywhere on the supplied CD.

The authors did not attempt to compile or execute the program in a UNIX or LINUX computer, see earlier comments from the QAV (Lockheed Martin, 2010b) regarding the difficulties of using VOACAP in these types of operating systems.

C. Producing Usable Output Data

The VOACAP output is produced in files using XML data structures (see sample test case example in Appendix B). For the areal coverage and point-to-point sample test cases (one each) the output numbers were compared directly with the supplied examples. However, performing a manual inspection of all the test cases (in Table 1, below) was not practical because of (1) the large amount of data, even for just one run, (2) the comparison programs did not readily produce the data in the same formats for easy comparison and (3) to evaluate the accuracy and realism of the many test cases, graphical displays were required. No plotting programs were provided with the CD. Therefore, the authors wrote several computer programs using Matlab to parse the output data and plot the results in similar forms as the comparison programs. This included contour plots showing the global field strength coverage and time series plots showing the 24 hour variations field strength from the point-to-point output data.

Once the data had been parsed, it was relatively straightforward to use GIS mapping tools to produce global coverage diagrams such as Figure 1 below and allow easy comparisons with the other model outputs.

Producing a MUF/LUF diagram was more difficult. Although the XML input parameter “Method” in the input file includes several options for choosing MUF and LUF outputs for a particular 24 hour period, only field strength is output for all Method choices. There was no documentation on how to produce a MUF/LUF time series for a 24 hour (or any other) period. Therefore, to allow comparison of the MUF/LUF predictions with the comparison programs, the point-to-point program was run using the same inputs except the frequency was varied from 2 to 30 MHz, and the field strength time series outputs for each frequency were stored in uniquely named data files. A Matlab program was created that would take the output for each frequency to create an array of predicted field strengths as a function of time and frequency. A contour plot of this array produced a color coded field strength plot as function of time (X axis) and frequency (Y-Axis), see Figure 3, below. This is not the same thing as a MUF/LUF diagram, which is not a contour plot but rather a time series of lines showing the specific MUF and LUF frequency values for a particular path and time interval. However, the field strength contour plot is very similar to a MUF/LUF diagram (both show time and frequency on the X and Y axes) and usually there are regions with sharp drop-offs in field strength in time-frequency space that can be used to make “eyeball” estimates of the MUF and LUF time series. The online version of VOACAP produced circuit reliability (%) contour plots in time-frequency space; this parameter is derived from field strength and thus allows qualitative visual comparisons. To produce true MUF/LUF diagrams, a threshold field strength would need to be determined and from this the MUF and LUF for each time step identified and plotted as a line time series. Although this would be an important step in an operational implementation of VOACAP, it was not required for this CIMREP and therefore not attempted.

Several other output data parameters besides field strength are required for any user application product based on VOACAP, such as NITES-NEXT, according to OAML-SDD-96 (2010c). (See section II.B.2 above) including Signal-to-noise Ratio (SNR), Reliability, Required Power Gain, Signal Power, MUF, LUF and Propagation

Angle and several others, but these parameters, are not in the output files. As noted, MUF and LUF outputs are listed available output parameters in the online versions of VOACAP, but these or any of the other output options were not available in the version submitted for inclusion in OAML.

D. Sample Test Case Results

1. Areal Coverage

The provided CD had XML text files that contained the numerical ouput for the areal coverage sample test case (see Appendix A for the exact input parameters specifications used and Appendix B for the numerical output files). A comparison of the supplied test case output with the output produced by authors showed identical values in both cases. This demonstrates that the areal coverage part of the program was correctly implemented.

Figure 2 shows global coverage diagrams of the output produced by the authors with similar contour plots produced by AREPS and the online version of VOACAP, respectively. For AREPS and the online VOACAP, not all the same input parameters as the CD VOACAP were available; but the authors tried to match the inputs as best as possible. Also the authors were unable to plot the same output parameter in each of the three model versions. For the VOACAP being evaluated here, field strength is plotted; for the AREPS version, signal-to-noise ratio at required reliability (in this case 90%) is plotted; for the online version of VOACAP, circuit reliability is plotted. For these reasons, the contour plots shown in Figure 2 do not look identical. However they are very similar and the authors interpret this to mean that the CD version of VOACAP is accurately producing the same results (or nearly the same) results as the AREPS and online versions. The authors also note that the coverage diagram makes sense from a physical point of view: for the relatively low frequency used (10 MHz) one expects that the field strength to more or less fall off with distance and with no obvious skip and bounce patterns. Other cases using higher frequencies (not shown here) produced patterns that showed the expected skip features and also reasonable behavior with respect to daytime and nighttime coverage, such as more daytime absorption and polar region effects. The authors conclude that the version of VOACAP submitted for inclusion in the OAML appears to be correctly implemented and produces accurate predictions.

2. Point-to-Point Time Series

The authors performed a similar comparison (as the areal coverage test above) for the point-to-point output fields using the sample test data file output on the supplied CD. As with the areal coverage, the point-to-point output fields were identical, indicating that VOACAP was correctly implemented.

As described in Section IV.C, the authors developed code that allowed the VOACAP output to be compared with field strength (or proxies) time series as a function of time and frequency. For this comparison the authors used the same sample test case inputs, with the exception of frequency which was varied by 1 Mhz increments from 2 Mhz to 30 Mhz, as required to produce the appropriate graphics for comparison with the

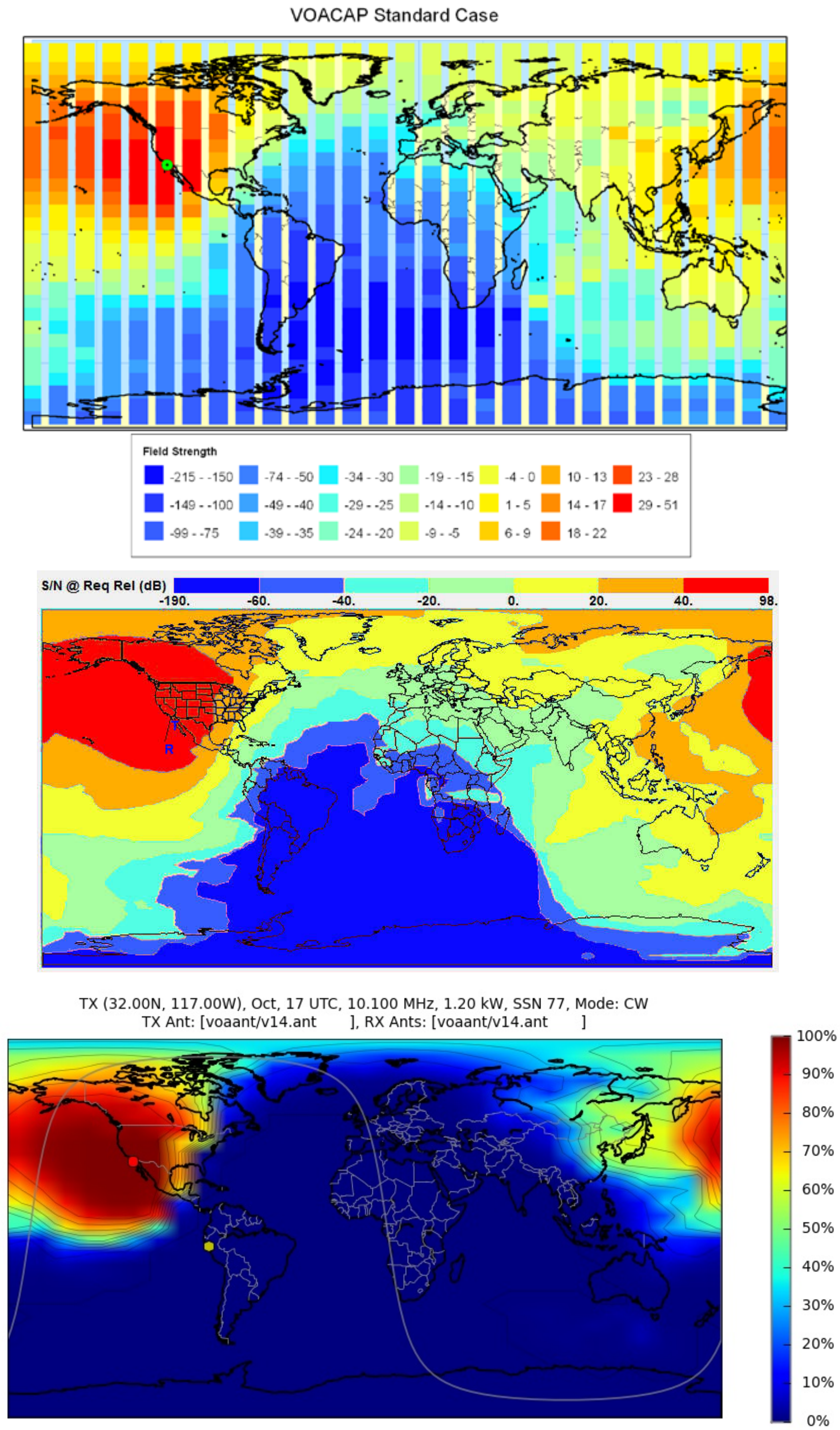

Figure 2. Contour plots showing areal coverage for the sample test case for VOACAP (top panel), AREPS (middle panel), and the online version of VOACAP (bottom panel). The three panels show field strenth (dBu), Signal to noise ratio at 90% reliability (dB) and circuit reliability (%) respectively. Although different, these parameters are all measures of signal power and show similar patterns between the different models.

AREPS and online VOACAP versions (Figure 3). As before, it was not possible to produce exactly the same contour colors as the online VOACAP nor be certain that all the inputs were identical. Also, as before, different output parameters were plotted for the different model versions. However, the three figures show a very similar pattern, and the expected diurnal changes are present. This is more evidence that VOACAP is correctly implemented and producing apparently accurate results.

E. Input Parameter Space Test Results

According to the OAML-SDD-96 (2010b) documentation, a variety of output parameters are available from VOACAP, although this is not the case in the submitted version. For example by choosing the "Method" parameter equal to 20 in the input file, a "complete system performance" is supposed to be available, this includes a variety of output variables including Signal-to-noise Ratio (SNR) at all modes, Reliability (% chance of successful comms), Required Power Gain, Signal Power, Probability of Occurrence, MUF and LUF. However, the only output parameter generated was Field Strength at Receiver in dBu units. This was the same output parameter provided in the sample test case described above. The authors tried using different values of the "Methods" including one that the documentation stated would produce a MUF/LUF table. However, only Field Strength was produced in the ouput files. Therefore, the authors were only able to evaluate the VOACAP signal strength output parameter.

Changing the Method input parameter produced errors and failure to execute in some cases. For example setting Method = 20 in the sample test case *point-to-point* input file produced an error statement. In the sample test case *areal coverage* input file, the Method was set to 20 and the program executed properly. Apparently different Method values require different input parameters to be specified. These issues were not discussed in any of the available documentation.

The authors executed point-to-point predictions using the stated minimum and maximum value for a variety of parameters (summarized in Table 1). For all of these cases the program appeared to execute properly and field strength values were produced in the output file. In many cases, changing the input parameters had no effect on the outputted field strength; these cases are indicated by the word "same" in the Table 1 "Notes" column. This was expected in most cases for parameters such as "ReqSignalToNoiseRatio" that do not affect field strength. However, the "Geomagnetic Index" would be expected to affect field strength and yet no differences in output were noted when this input parameter was changed. Unfortunately because the authors were only able to produce field strength output, they were not able to test the effects of input variables related to receiver characteristics or man-made noise, for example. Parameters such as Transmitter Frequency, Receiver Latitude/Longitude and Sunspot number did produce differences in the field strength output, as expected.

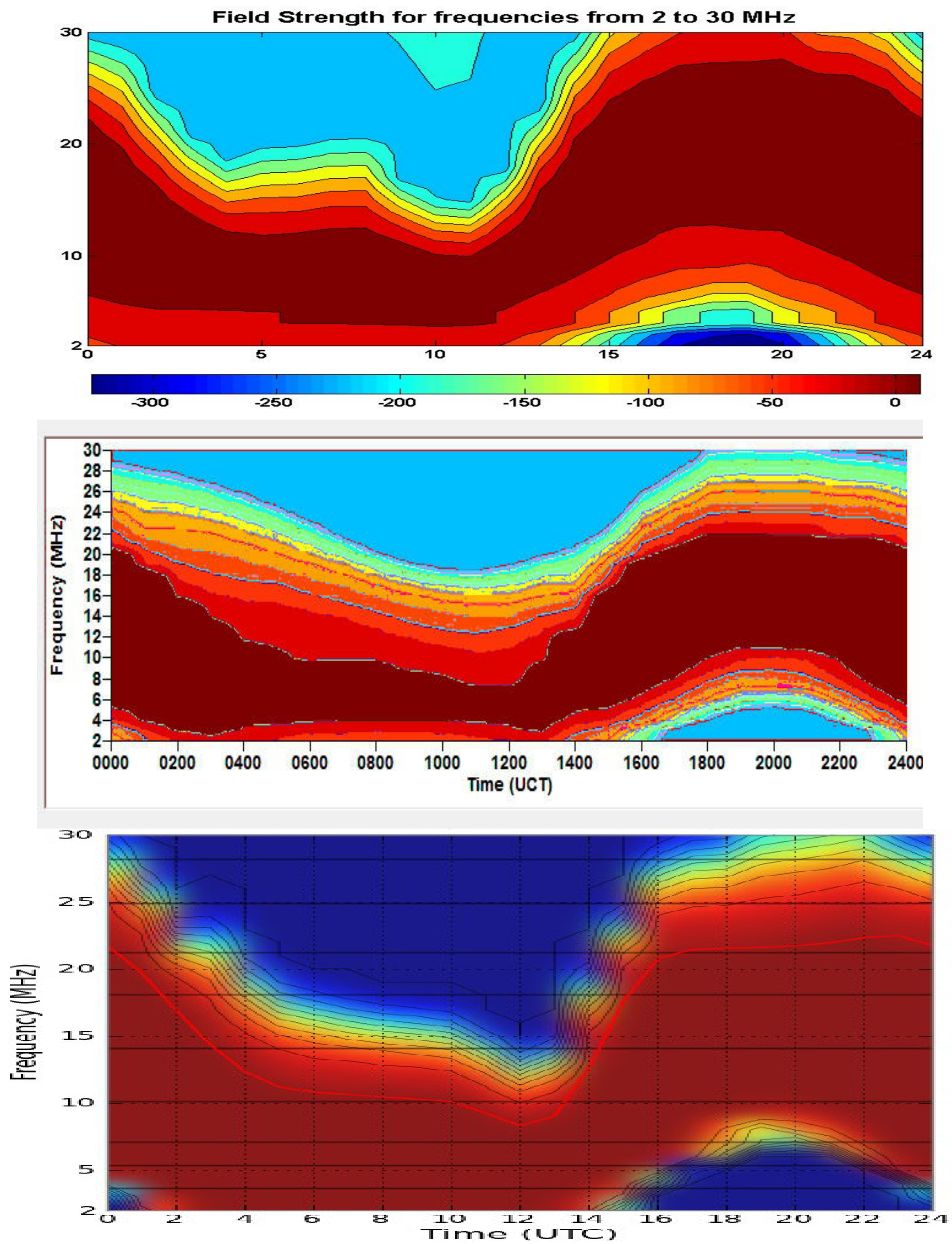

Figure 3. Contour plots showing 24 hour time variations at various frequencies for the point-to-point test sample case for VOACAP (top panel, field strength dBu), AREPS (middle panel, signal-to-noise ratio, dB), and the online version of VOACAP (bottom panel, circuit reliability %). The contour colors are the same as the respective panels in Figure 2, i.e. stronger signals in red, weaker in blue. As in Figure 2, these parameters are all measures of signal power and show similar patterns between the different models. These plots are similar to MUF/LUF diagrams; the MUF would be somwhere at the top of the red areas while the LUF would be at the bottom of the red areas, or the default value of 2 Mhz if no blue area exists below.

Table 1 Parameter Space Test Summary

Case	Parameter	Value	Output filename	Notes
1		Default	VOA_P2P_stdcase.xml	
2	Path	Long	case2_output.xml	Same result as std case
3a	ReqCircuitReliability	1	case3a_output.xml	Same
3b	“	50	Case3b_output.xml	Same
4a	ReqSignalToNoiseRatio	-30	Case4a_output.xml	Same
4b	“	99	Case4b_output.xml	Same
5a	MultipathPowerTolerance	0	Case5a_output.xml	Same
5b	“	40	Case5b_output.xml	Same
6a	MultipathTimeDelay	0	Case6a_output.xml	Same
6b	“	99.99	Case6b_output.xml	Same
7a	Transmitter frequency	2	Case7a_output.xml	Also changed DesignFreq to match. Different
7b	“	30	Case7b_output.xml	“ Different
8a	Type	02	Case8a_output.xml	Change receiver type also Same as standard case
8b	Type	47	Case8b_output.xml	Change receiver type also Same as standard case
9a	Latitude	-90	Case9a_output.xml	Same
9b	“	0	Case9b_output.xml	Same
10a	Orientation	90	Case10a_output.xml	Same as standard case
10b	“	180	Case10b_output.xml	Same as standard case
11a	MinTakeoffAngle	40	Case11a_output.xml	Same
12a	Power	0.001	Case12a_output.xml	Same
12b	“	1000	Case12b_output.xml	Same
12c	“	9999	Case12c_output.xml	Same
13a	Receiver Ant Gain	-90	Case13a_output.xml	Same as standard case
13b	“	90	Case13b_output.xml	Same as standard case
14a	Receiver Latitude / longitude	-32 -117	Case14a_output.xml	Same
14b	Receiver Lat / Long	32	Case14b_output.xml	Same

		117		
15	Sunspot number	250	Case15_output.xml	Same
16	IonModel	URSI88	Case16_output.xml	Same as standard case
17a	MultiplierELayer	0.1	Case17a_output.xml	Similar to standard case for some hours, but different for others
17b	Multiplier ELayer	3	Case17b_output.xml	Same
18a	Geomagnetic Index	0	Case18a_output.xml	Same as standard case
18b	Geomagnetic Index	8	Case18b_output.xml	Same as standard case

V. Changes Required and Specific Recommendations

This section describes the changes that the authors believe should be implemented before VOCAP is officially included in the OAML library. It is possible that some of these suggestions are not required for inclusion in OAML. Therefore this section should be considered to represent a basis for discussion among the developers and stakeholders and not necessarily as absolute requirements.

A. Model Physics

The authors were satisfied that the physical and statistical integrity of the VOACAP model, including the CD version produced by SSC-Pacific, is sound, for the various reasons discussed earlier. The model uses a statistical approach and it is not likley that the model prediction would ever produce perfect predictions for a particular situation. However, we believe that an inaccurate prediction would more likely be due to errors in the input parameters or misconceptions by the users rather than errors in the representation of physical processes in the model. No changes in the actual core model code are required at this time for inclusion in OAML. However, as documented in the online VOACAP web sites, Greg Hand and perhaps other HF experts may make changes to the code as bugs or other problems are discovered. We recommend that if a Navy Version of VOACAP is included in the OAML, someone should be responsible for keeping abreast of monitoring changes that are being done to other versions of VOACAP and decide whether these are relevent and significant enough to merit modifying the Navy implementation.

VOACAP predictions do not directly incorporate day-to-day space weather effects, but instead are based on monthly averages of mostly benign space weather situations. There appears to be a capability to include space weather effects by use of the “layer multiplier” input variables. The program would be considerably more useful if there was some way that space weather effects could be either automatically or at least more easily incorporated into the program, either by use of the layer multipliers or some other method. Or some guidance could be provided in documentation.

B. Implementing VOACAP

The authors suggest that a set-up utility be created that could automate the implementation procedure as much as possible. This could include creating a logical default directory structure and naming conventions.

C. Output Parameters

Field strength at receiver is the only output parameter that is produced and output in the current version as implemented. According to the Software Requirements Specification (OAML-SDD-96, 2010c), 21 output variables are required. Parameters such as MUF and LUF are essential for almost every application of an HF prediction program, but they are not directly available in the output. Although only having Field Strength at Reciever may be sufficient to meet OAML needs (potential developers can use Field Strength to derive other parameters), the authors recommend that other output variables be made available in an OAML version. The rationale is that as long as the input variables (such as man-made noise, Tx and Rx features, etc.) are in place in the available versions of VOACAP to produce output variables other than Field Strength, these should be available in an OAML version to avoid the the extra development cost of calculating these values outside of the core version available from OAML. In the authors' opinion, VOACAP should have the ability to provide the user with MUF/LUF outputs and other important output parameters, but whether this is actually required needs to be decided by others.

Although it is expected that tactical decision aid developers would produce their own methods for visually displaying the output field in areal coverage diagrams and time series plots for MUF/LUF, reliability etc., it would be helpful to have some type of plotting capability provided as a development aide. The authors created Matlab programs for this purpose and can make these available.

The Software Requirements Specification (OAML-SDD-96, 2010c) states on page 17 "NTIA recommends that VOACAP not be used for a LUF calculation" due to a problem with negative values being produced when the required reliability is not met. This is a strange statement that needs to be examined in more detail. Apparently this issue has been overcome or ignored in the AREPS implementation.

D. Documentation

Several changes and additions to the documentation should be created, described in the following bullets.

- There should be a readme.txt file placed in the top directory layer of the CD with clear instructions on how to implement and execute VOACAP or at least clear references to where this information can be found. This would not be difficult to do and would save considerable effort and wasted time by potential developers who need to use this product.

- There needs to be documentation that better describes the Method parameters and what other input parameters need to be provided in the XML fields for each of the possible Method values.

- There needs to be documentation, perhaps with screen shots that shows the step by step procedures required to be able to make VOACAP properly execute.

- The needs to be documentation that clearly states where more information on VOACAP can be obtained, e.g. suggested web links such as http://www.voacap.com/.

- There need to be links to HF training material in the documentation (see next section)

E. Training Requirements

Successfully use of VOACAP requires some knowledge of HF propagation, HF radio systems and antennas. While an inexperienced person could probably run the program, the results would most likely be in error. As a result of untrained use, the program would get a reputation of not being an accurate prediction tool, and its use among Navy personnel would drop.

Many aspects of the training need to be provided to users of VOACAP; this report will not discuss all the details. One notable example would be understanding how to incorporate space weather effects into the VOACAP inputs; how to do this was not apparent to the authors.

Although training is not the responsibility of OAML, it should be made clear that this is necessary for both tactical decision aid developers who would implement VOACAP and also the end users of such products. Because HF is not extensively used by the Navy, the motivation for providing such training may be lacking. The training issue needs to be addressed if the Navy is serious about using VOACAP for operational use.

There should be links to educational material on HF propagation in the VOACAP documentation. At the very least, the users should be made aware of the most common problems that are likely to result in inaccurate predictions. An excellent example of this is the "Ten Common Mistakes in Using VOACAP" by Perkiömäki at http://www.voacap.com/10mistakes.html. Users also need to be aware that VOACAP only predicts skywave propagation and therefore may underpredict signal strengths at medium ranges (< 1500 km) where surface wave propagation can be significant, particularily for lower frequencies in the HF range.

F. Operating Systems

The executable version of VOACAP only runs on the Windows XP operating system, which is essentially obsolete. Although individual developers may be able to compile the source code for different operating systems, this may be a difficult task. The authors recommend that the compilation procedure be tested on more recent systems (including 64-bit) such as Windows 7 and/or Windows 8.

A decision must be made on whether VOACAP should have the ability to operate on a LINUX or UNIX system. Based on the descriptions in the QAV (Lockheed Martin, 2010b), this requires considerable changes to the code; their intitial attempts were unsuccessful. However, due to some recent work by Jim Watson, affilation unknown, it appears that a version of VOACAP that runs under UNIX or LINUX is now available at no cost. Details can be found at http://www.qsl.net/hz1jw/voacapl/index.html. If it is determined that this capability is needed for Navy use, the authors recommend that the new code developed by Watson be tested and included in OAML.

VI. Developer Response to Findings and Recommendations

P. Guest met with the official "developer" of the submitted VOACAP program at SSC-Pacific, APB in San Diego CA, Ms. Amalia Barrios, on November 7, 2012. The word "developer" is in quotes because Ms. Barrios was not actually the primary developer of this version of VOACAP or its implementation in AREPS; that person retired from SSC-Pac after the VOACAP version evaluated in the report was put on the provided CD. Ms. Barrios maintains the VOACAP implementation in AREPS and has considerable familiarity with the program, but she acknowledges that she is not an HF modeling expert and is not familiar with all the details of the VOACAP core model and the related files on the CD version evaluated by the authors.

Ms. Barrios and Dr. Guest discussed in some detail most of the issues referenced in this report. Ms. Barrios agreed with all the findings and recommendations presented by the authors of this report. She stated that due to lack of resources and available HF expertise, SSC-Pac was not able at the current time to address the issues identified. If resources, including the hiring or contracting of an HF modeling expert, were available to SSC-Pac, Ms. Barrios stated that SSC-Pac would be able to address the issues identified in this report and create a version of VOACAP suitable for inclusion in the OAML.

Ms. Barrios was recently provided with a final draft copy of this report and commented via email. She confirmed that she agreed with the results and recommendations, except that she noted that it was the intent of SSC-Pac to only include signal strength as an output parameter. The OAML submitted version is a model, not an application of VOACAP, similar to APM, the model, being incorporated into the AREPS application. An application can then use the results of the model to derive the other parameters such as Signal to Noise Ratio, Reliability, MUF/LUF etc. She also emphasized the point that no one at SSC-Pac or elsewhere in the Navy "really officially maintains it".

VII. Conclusions and Final Recommendations

The authors do not recommend that the current version of VOACAP be included in OAML. The core physics and statistics in VOACAP are sound, and the program is considered to be the "gold standard" by many HF experts. This product could potentially be very useful to the US Navy. However, the version provided to the authors of this report as a candidate for inclusion into OAML is unacceptable in many ways. Installing the program on a PC was not intuitive, and required debugging before it would run. The supplied FORTRAN compiled executable file only worked on Window XP operating systems. The FORTRAN source code could potentially be compiled on other systems, but this needs to be tested. Implemention on UNIX/LINUX systems would require substantial changes or the use of newer versions of VOACAP developed outside the Navy.

The submitted program produces outputs of Field Strength at Receiver only. This may be sufficient for its inclusion in OAML. However, it is essential for any useful application of an OAML VOACAP that the 21 other recommended output variables be available to the final user. It may be cost effective to include options for these useful and essential parameters in an OAML version of VOACAP, relieving later developers of this task.

The documentation required to install and execute the program is hard to find, scattered and incomplete. This needs to be improved. Other tools, such as plotting programs to display the results would also be helpful, although perhaps not required for inclusion in OAML.

Although not necessarily essential for inclusion in OAML, if VOACAP is to be used by developers and operators of HF systems, they should be trained on basic HF principles as well as the specific use of the Navy Version of VOACAP. This is not a product that could be successfully employed by a casual user without such training.

If the Navy is going to make the commitment to include VOACAP in OAML, resources will need to be provided for further development of the product to address the issues discussed in this report. Another important resource requirement is to have a "go-to" person who is highly knowledgeable about the OAML version of VOACAP and be available for consultation when the inevitable difficulties arise from developers and end users in the future. The Navy needs to determine whether it is worth the expense needed to include VOACAP in the OAML, when anyone within DoD can very easily get a working version of VOACAP online. Development efforts could focus on providing the specific system, antenna, target and environmental input parameters and procedures required for accurate predictions of operational HF communication systems using already available applications rather than developing a complete HF prediction package.

VIII. Disclaimer

The views expressed in this report represent the best good faith efforts of the authors to evaluate the appropriateness of VOACAP for inclusion in OAML. However, the opinions expressed here should not be considered to represent official US Navy policy or opinions. Any reference to a commercial product does not imply an endorsement of that product by the US Navy or any part of the US Government.

IX. References

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OAML-SDD-96, *Software Requirements Specifications for the VOACAP Version 05.0119W Model*, December, 2010c

OAML-SDD-96, *Software Modification Document for the VOACAP Version 05.0119W Model*, December, 2010d

X. Appendix A – Test Sample Input Files

A. Areal Coverage Sample Test case Input File


```
<?xml version="1.0" encoding="UTF-8" ?>
  <RFPS>
    <VOACAP ID="any" ShowInput="On">
      <Method>20</Method>
      <DateTime>2009-10-07T17:04:47Z</DateTime>
      <Path>Short</Path>
      <ReqCircuitReliability Unit="%">90</ReqCircuitReliability>
      <ReqSignalToNoiseRatio Unit="dB">20</ReqSignalToNoiseRatio>
      <MultipathPowerTolerance Unit="dB">3</MultipathPowerTolerance>
      <MultipathTimeDelay Unit="usec">0.1</MultipathTimeDelay>
      <Transmitter>
        <Frequency Unit="MHz">10</Frequency>
        <Type>0</Type>
        <Latitude Unit="deg">32</Latitude>
        <Longitude Unit="deg">-117</Longitude>
        <Orientation Unit="deg">0</Orientation>
        <MinTakeoffAngle Unit="deg">0</MinTakeoffAngle>
        <Power Unit="kW">5</Power>
        <DesignFreq Unit="MHz">10</DesignFreq>
      </Transmitter>
      <Circuit>
        <Latitude Unit="deg">32</Latitude>
        <Longitude Unit="deg">-117</Longitude>
        <CenterName>Location name</CenterName>
        <WesternBoundary Unit="deg">-180</WesternBoundary>
        <EasternBoundary Unit="deg">180</EasternBoundary>
        <NorthernBoundary Unit="deg">84.30667</NorthernBoundary>
        <SouthernBoundary Unit="deg">-90</SouthernBoundary>
        <GridType>1</GridType>
        <GridSize>30</GridSize>
      </Circuit>
      <Receiver>
        <Type>0</Type>
        <AntGain Unit="dBi">0</AntGain>
        <Orientation Unit="deg">0</Orientation>
      </Receiver>
      <Environment>
        <SunspotNum>75</SunspotNum>
        <IonModel>CCIR</IonModel>
        <MultiplierELayer>1</MultiplierELayer>
        <MultiplierF1Layer>1</MultiplierF1Layer>
        <MultiplierF2Layer>1</MultiplierF2Layer>
```

```
      <MultiplierSporELayer>1</MultiplierSporELayer>
      <ManMadeNoise Unit="-dBw/Hz">150</ManMadeNoise>
    </Environment>
  </VOACAP>
</RFPS>
```


B. Point-to-point Sample Test Case Input File


```
<?xml version="1.0" encoding="UTF-8" ?>
  <RFPS>
    <VOACAP ID="any" ShowInput="On">
      <Method>26</Method>
      <DateTime>2009-10-07T17:04:47Z</DateTime>
      <Path>Short</Path>
      <ReqCircuitReliability Unit="%">90</ReqCircuitReliability>
      <ReqSignalToNoiseRatio Unit="dB">20</ReqSignalToNoiseRatio>
      <MultipathPowerTolerance Unit="dB">3</MultipathPowerTolerance>
      <MultipathTimeDelay Unit="usec">0.1</MultipathTimeDelay>
      <Transmitter>
        <Frequency Unit="MHz">10.00</Frequency>
        <Type>0</Type>
        <Latitude Unit="deg">32</Latitude>
        <Longitude Unit="deg">-117</Longitude>
        <Orientation Unit="deg">0</Orientation>
        <MinTakeoffAngle Unit="deg">0</MinTakeoffAngle>
        <Power Unit="kW">5</Power>
        <DesignFreq Unit="MHz">10.000</DesignFreq>
      </Transmitter>
      <Receiver>
        <Type>0</Type>
        <AntGain Unit="dBi">0</AntGain>
        <Latitude Unit="deg">20</Latitude>
        <Longitude Unit="deg">-120</Longitude>
      </Receiver>
      <Environment>
        <SunspotNum>75</SunspotNum>
        <IonModel>CCIR</IonModel>
        <MultiplierELayer>1</MultiplierELayer>
        <MultiplierF1Layer>1</MultiplierF1Layer>
        <MultiplierF2Layer>1</MultiplierF2Layer>
        <MultiplierSporELayer>1</MultiplierSporELayer>
        <ManMadeNoise Unit="-dBw/Hz">150.4</ManMadeNoise>
        <GeomagneticIndex>4</GeomagneticIndex>
      </Environment>
    </VOACAP>
  </RFPS>
```

XI. Appendix B – Test Sample Output Files

A. Areal Coverage Sample Test Case Output Files (first few lines)

<AreaData>
<GridPoint>
<Latitude Units="Deg">-90</Latitude>
<Longitude Units="Deg">0</Longitude>
<FieldStrength Units="dBu">-86.4</FieldStrength>
</GridPoint>
<GridPoint>
<Latitude Units="Deg">-83.9897</Latitude>
<Longitude Units="Deg">-180</Longitude>
<FieldStrength Units="dBu">-73.1</FieldStrength>
</GridPoint>
<GridPoint>
<Latitude Units="Deg">-83.9897</Latitude>
<Longitude Units="Deg">-167.5862</Longitude>
<FieldStrength Units="dBu">-74.3</FieldStrength>
</GridPoint>
<GridPoint>
<Latitude Units="Deg">-83.9897</Latitude>
<Longitude Units="Deg">-155.1724</Longitude>
<FieldStrength Units="dBu">-75.6</FieldStrength>
</GridPoint>

(This is a long file that includes global data, just the first few lines are showm above)

B. Point-to-point sample test case input file (entire file)

<PointData>
<Point>
<Hour>0</Hour>
<FieldStrength Units="dBu">48</FieldStrength>
</Point>
<Point>
<Hour>1</Hour>
<FieldStrength Units="dBu">50</FieldStrength>
</Point>
<Point>
<Hour>2</Hour>
<FieldStrength Units="dBu">53</FieldStrength>
</Point>
<Point>
<Hour>3</Hour>
<FieldStrength Units="dBu">55</FieldStrength>
</Point>
<Point>

<Hour>4</Hour>
<FieldStrength Units="dBu">54</FieldStrength>
</Point>
<Point>
<Hour>5</Hour>
<FieldStrength Units="dBu">55</FieldStrength>
</Point>
<Point>
<Hour>6</Hour>
<FieldStrength Units="dBu">51</FieldStrength>
</Point>
<Point>
<Hour>7</Hour>
<FieldStrength Units="dBu">50</FieldStrength>
</Point>
<Point>
<Hour>8</Hour>
<FieldStrength Units="dBu">49</FieldStrength>
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<Hour>9</Hour>
<FieldStrength Units="dBu">47</FieldStrength>
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<Hour>10</Hour>
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<Hour>11</Hour>
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<Hour>12</Hour>
<FieldStrength Units="dBu">41</FieldStrength>
</Point>
<Point>
<Hour>13</Hour>
<FieldStrength Units="dBu">48</FieldStrength>
</Point>
<Point>
<Hour>14</Hour>
<FieldStrength Units="dBu">49</FieldStrength>
</Point>
<Point>
<Hour>15</Hour>
<FieldStrength Units="dBu">48</FieldStrength>

```
      </Point>
      <Point>
        <Hour>16</Hour>
        <FieldStrength Units="dBu">47</FieldStrength>
      </Point>
      <Point>
        <Hour>17</Hour>
        <FieldStrength Units="dBu">42</FieldStrength>
      </Point>
      <Point>
        <Hour>18</Hour>
        <FieldStrength Units="dBu">34</FieldStrength>
      </Point>
      <Point>
        <Hour>19</Hour>
        <FieldStrength Units="dBu">30</FieldStrength>
      </Point>
      <Point>
        <Hour>20</Hour>
        <FieldStrength Units="dBu">29</FieldStrength>
      </Point>
      <Point>
        <Hour>21</Hour>
        <FieldStrength Units="dBu">31</FieldStrength>
      </Point>
      <Point>
        <Hour>22</Hour>
        <FieldStrength Units="dBu">37</FieldStrength>
      </Point>
      <Point>
        <Hour>23</Hour>
        <FieldStrength Units="dBu">45</FieldStrength>
      </Point>
      <Point>
        <Hour>24</Hour>
        <FieldStrength Units="dBu">48</FieldStrength>
      </Point>
    </PointData>
  </VOACAP_Results>
</RFPS_Output>
```


XII. Appendix C – VOACAP CD Readme File

```
To use RFPS:
 1) You must have the Microsoft .NET Framework 2.0 on your computer.
(Its free)
 2) Unzip RFPS.zip to C:\Program Files\RFPS
```

You should now have a file: 'C:\Program Files\RFPS\Rfps.exe'
3) You may have to modify C:\Program Files\RFPS\Config.XML to specify where
your DTED folder is located.
4) Double click Rfps_FileIO.bat and then look in Data\Output for the results.

===

Contents:

```
  .\RFPS\     RFPS Executable and all support DLLs
              Also Config.XML which must be modified (see below)

    RFPS.exe           65,536 10/13/09 Main program

    Apm37NetLib.dll     77,824 10/13/09 Routines used to interface with ApmLib37.dll
    ApmLib37.dll        974,848 09/02/08 Fortran DLL version 3.7 using APM version 2.3.09
    ArepsDB.dll         69,632 10/13/09 Routines used to manipulate the database
    GeLDted.dll         40,960 10/13/09 Routines used to read the DTED database files.
    GeLGCD.dll          49,152 10/13/09 Routines used to calculate Great circle distances.
    GeLPacks.dll       397,312 10/13/09 General purpose routines.
    LfMf3Lib.dll       913,408 09/29/09 Fortran coded DLL of LFMF model. version 3.0
    LFMFLib.dll         32,768 10/13/09 Routines used to interface with LfMf3Lib.dll
    VoacapLib.dll       49,152 10/13/09 Routines used to interface with VoacapLib30.dll
    VoacapLib30.dll  1,519,616 10/13/09 Fortran coded DLL of Voacap model. version 3.0

    Config.XML         Configuration file. (You may need to modify this file.)

    Rfps_FileIO.bat   Example of a Windows batch file used to test File I/O
       RFPS.exe /infile "Data\Input\APM_absorb.xml" /outfile "Data\Output\APM_absorb.xml"
       RFPS.exe /infile "Data\Input\VOA_area.xml" /outfile "Data\Output\VOA_area.xml"

    Rfps_stdin.bat      Example of a Windows batch file used to test Standard I/O
         RFPS /stdin <Data\Input\APM_absorb.xml >Data\Output\APM_absorb.xml

    Data              Folder containing data files

    Data\System\ArepsDataBase.XML
    Data\Ionosphere
           Folder containing all neccessary files for VOACAP runs.
           Do not modify this folder or its contents.
```

Data\Input
Sample XML input files
Data\Output
Sample output files generated by RFPS using files in Data\Input

==
Sample Config.XML file used in RFPS:

```
<?xml version="1.0"?>
<Configuration>
  <SystemDatabase>C:\Program Files\RFPS\Data\System\ArepsDatabase.XML</SystemDatabase>
  <DtedFolder>C:\DTED</DtedFolder>
  <DataFolder>C:\Program Files\RFPS\Data</DataFolder>
</Configuration>
```

notes: The contents of '<DtedFolder>' must contain subfolders such as W117 which in turn contain files such as N32.DT1.
Example with the above configuration: 'C:\DTED\W117\N32.DT1'

The contents of '<DataFolder>' must contain the subfolder 'Ionosphere'
Example with the above configuration: 'C:\Program files\RFPS\Data\Ionoshpere'

<SystemDatabase> does NOT have to be the related to <DataFolder> although its a good way to organize it.
<DtedFolder> can reside on a seperate server. i.e. '\\Server\DTED'

==
RFPS Usage:
Command line arguments: (not case sensitive)

```
/stdin               Reads data from standard input.
/stdout              Outputs data to standard output.
/infile pathname     Reads from file if not Stdin  (Ignored if /stdin is used)
/outfile pathname    Writes data to outfile.  (Can be used in conjunction with /stdout)
```

Sample:

```
RFPS.EXE /stdin <Data\absorb.xml >Data\absorb_Out.xml
RFPS.EXE /infile "Data\absorb.xml" /outfile "Data\absorb_out2.xml"
```

==
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